Remarks About Fields of High Intensity

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Abstract

At high field strength any known material will break down by
the production of electrons and ions. At a higher field
strength, massive production of pairs will occur. This
phenomenon is discussed when heavy ions of $\gamma \approx 100$ collide.
Even when the heavy ions approach to within one nuclear
radius, pair production involving electrons and mesons must
be expected. The application to magnetic monopoles is
discussed.

Research on high-intensity lasers led to the investigation of non-linear

effects in optics. Electric field-strengths of 10^5 volts/cm are

commonplace--even over extensive regions. If such fields are maintained for

sufficient time they cause electric breakdown in air. In the microwave region

non-linear effects should be expected in metals. At very high frequencies

remarkable effects will occur even in vacuum.

High-energy physics concentrates on collision between particles. High

intensity fields give rise to pair production involving a variety of

particles. The frequency ω_m required to produce a pair of particles with

mass m is

$$\omega_m = \frac{2\ mc^2}{\hbar}$$

If a high field is produced during a short pulse, pulse of an appropriate duration, τ, will produce pairs, provided that ω_m does not greatly exceed $1/\tau$. For longer pulses the probability of pair production is apt to decrease as

$$e^{-\tau\omega_m}$$

For shorter pulses, pair production will decrease as

$$(\tau\omega_m)^2$$

The field strength required for ample pair production is determined by the condition that the force $\mathscr{E}e$ that acts on an elementary charge multiplied by the Compton wavelength $\hbar/mc$ should be comparable to mc^2. This gives the critical field strength

$$\mathscr{E}_{crit} = (mc^2)^2/e\hbar c.$$

Near an electron this field strength is reached at a radius

$$\left[\frac{e^2}{mc^2} \cdot \frac{\hbar}{mc} \right]^{1/2}$$

that is at the geometric mean between the classical radius of the electron and the Compton wavelength. Near the surface of a uranium nucleus similar fields occur. But the distances over which pairs could be produced are too short so that actual pair-production is prohibited.

The situation is quite different when two relavistic particles collide. In the Superconducting Super Collider (SSC), protons of $\gamma = 20,000$ meet. In the Relativistic Heavy Ion Collider (RHIC), two uranium nuclei with $\gamma = 100$ may interact. Much higher frequencies and energies are reached in the SSC. The maximum field strength is also somewhat higher in the SSC. But in the SSC the duration of the encounter τ is so short that the dependence of the factor $(\tau\omega_m)^2$ limits the number of pairs that one can expect.

The case of overlapping fields for uranium nuclei has been discussed by H. Gould[1] and M. S. Weiss[2] when two nuclei moving with $\gamma = 100$ in opposite directions collide. They have shown that there is ample production of electron-positron pairs, production of μ-mesons and even some production of τ-mesons. This is due to the fact that the electric fields add while the magnetic fields subtract so that for a short period the invariant $\mathscr{E}^2 - \mathscr{H}^2$ becomes very large.

One should also notice that pair production will also occur when two uranium nuclei miss each other so that the nearest approach of the two surfaces is of the order of 10^{-12} cm. Then between the two nuclei the electric fields will subtract and the magnetic fields will add. $\mathscr{E}^2 - \mathscr{H}^2$ will become equally large (in absolute value). If τ is not much more than $\hbar/mc^2$ pair production can occur. The approximate upper limit of the rest energy is

$$mc^2 = \frac{\hbar c \gamma}{r_N}$$

when r_N is the radius of the colliding nuclei.

One must raise the question of the production of quark-antiquark pairs. According to the hypothesis of increasing interaction with increasing distance the pair production should be prevented. But one should expect the production of bound quark-antiquark pairs, that is of π mesons. Thus mesons and quark plasmas will be produced not only in the overlapping parts of the colliding nuclei but also in the free space around them or between them.

The case of close collisions without actual overlapping is interesting for three different reasons.

While such collisions are not effective for low γ-values and have not yet been observed, in the range of high γ-values they are more probable than actual contact.

Secondly, pair production by sudden negative values of $\mathscr{E}^2 - \mathscr{H}^2$ is a consequence of the mixing of negative energy and positive energy eigenfunctions of the Dirac equation in a strong magnetic field. Confirmation of this theoretical statement would be of some interest.

Finally, the experiment will have a bearing on the production of magnetic monopole-antipole pairs. This pair production is impeded under most conditions by the high value of μ, the monopole strength. For electric pair-production the attractive potential e^2/r is small compared to the kinetic energy $\hbar c/r$ connected with the uncertainty principle applied to a pair created at a distance r. The ratio is $e^2/\hbar c = 1/137$ and has the same value for the electron-positron or the proton-antiproton creation.

For a monopole-antipole creation the potential energy is μ^2/r and the
kinetic energy is $\hbar c/r$. The ratio will be $\mu^2/\hbar c \approx 137$. Therefore, pairs,
even if they are produced, will not be torn apart except to a distance $\dfrac{r_N}{\gamma}$.
This is the distance they can achieve with light velocity during the time of
encounter $\tau = \dfrac{1}{\gamma} \cdot \dfrac{r_N}{c}$. The similarity to the quarks is obvious. The
possibility of a connection between quarks and monopoles has been pointed out
by Julian Schwinger.[3]

Monopoles of a mass not greatly in excess of 10^9 eV, the limit imposed
by $mc^2 = \hbar/\tau$, could in principle be produced by the collision of heavy
nuclei at RHIC. It is quite unlikely that free monopoles will be actually
observed, because a similar process initiated by cosmic rays would have
already produced them.

High γ-value collisions between heavy ions can be studied for various
approaches of the collision partner. The energies and numbers of the
electrons and positrons produced will indicate the distance to which the ions
have approached. The mesons observed in coincidence can give a detailed
description of the collision process.

If indeed the quarks should have a monopole nature, this may result in a
greatly increased meson production for the near-miss type of collisions. In
this way a basically new type of meson formation may be demonstrated.

The SSC has the potential to expand our knowledge of physics into new
fields as will central collisions at RHIC to some extent. Peripheral

collisions at RHIC may not explore basically novel phenomena, but will permit the exploration of our present ideas for energies up to 10^{11} eV. For actual collisions involving the overlapping nuclei the simplicity of statistical mechanics will provide a new criterion of recent ideas. In the neighborhood of the nuclei processes in the vacuum involving particles around 10^9 eV could be explored. Experimentally the two kinds of processes could be separated.

The solidity of science depends on the completeness of information on which we build. Study of heavy-ion collisions could improve the informational basis for future progress.

References:

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2. M. S. Weiss, "Tau Meson Atoms at RHIC", UCRL-93603, October 1985, (published in Proceedings of Phase Space Approach to Nuclear Dynamics, M. Ditoro, Editor, World Scientific, Singapore, 1986).

3. J. Schwinger, Phys. Rev. 125, 397, (1962).